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SURFACE CHARACTERISATION USING IMAGE PROCESSING

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Abstract: *The complexity of surfaces in the human environment and the fast flow and transfer of information necessitates the modification of existing approaches or the implementation of new ones for the development and maintenance of surfaces in contact. The complete understanding and management of tribological processes, which are dynamic processes with an uncertain number of parameters, require the application of modern information and intelligent technologies. Analysis of surface topography often necessitates the utilization of sophisticated equipment. However, the availability of such equipment is not always guaranteed or justified. Therefore, there is a need to establish an environment where control can be achieved at any time. Therefore, this paper presents a methodology for analysing surface topography based on generating spatial surfaces using image processing from an optical microscope. By applying an appropriate threshold and segmenting the wear track, a series of 2D and 3D roughness parameters can be determined in the user-selected plane. This allows for faster determination of the defined parameters and provides an overview of the behaviour of surfaces in contact.*

Keywords: *Surface roughness, Surface characterisation, Image processing, Triboinformatics*

1. INTRODUCTION

Tribology is a highly important and rapidly developing multidisciplinary field. In recent years, research in this area has expanded to include nanotribology, biotribology, eco-tribology, and many others. The main goal of tribology is to reduce energy consumption, maintenance costs, and increase the reliability of systems by optimizing their operating conditions [1-3].

Nowadays, the complexity of systems is continuously increasing. As a result, developing and maintaining them requires modifying existing approaches or applying new ones [3]. The rapid flow and transfer of data have significantly influenced the advancement of tribological research and the management of tribological processes.

The development of triboinformatics has been facilitated by applying principles and concepts from data-based technologies such as big data, the Internet of Things, digital twins, and others [4]. This enables the establishment of tribological databases and standards through the continuous collection, storage, processing, analysis, and dissemination of fundamental tribological data.

The advanced development of information and intelligent technologies (such as machine learning, deep learning, etc.) has facilitated their diverse application in the field of triboinformatics. As a result, it is now possible to establish relationships and laws between input and output tribological parameters by utilizing mechanisms and methods for controlling and predicting contact conditions [5,6].

The topography of a surface plays an important role in meeting the requirements of modern society. Objects in our environment are defined by their boundary surfaces, which often have irregularities. Achieving the desired effect in surface contact requires specific irregularities in some cases, while in others it does not. By selecting the appropriate production process, components can be manufactured with a specific geometric structure for a particular application. The development of engineering technologies has resulted in increasingly complex working conditions and higher requirements for operational reliability and stability in industrial products and equipment [4,6].

From a tribological standpoint, the contact phenomena between surfaces have been studied for many years through various simulations, experiments, and engineering data. During the mutual movement of two surfaces, tribological processes occur, resulting in physical and chemical changes to the surfaces due to input parameters. This can lead to changes in geometry, material composition, and energy output parameters, such as friction, wear, speed, temperature, and dynamic behaviour. In other words, tribomechanical processes are highly complex, and optimizing surfaces in contact requires a systematic understanding of the mechanisms at play. This is a dynamic process that involves many uncertain parameters [6,7].

In mechanical systems, the surface structure and its characteristics determine the functional properties of the material. The topography of processed surfaces has a significant impact on the basic tribological properties of surfaces in contact, including thermal and electrical conductivity, friction, deformation, positional accuracy, and fatigue strength. As a result, characterizing surface roughness and topography is essential [7].

Numerous methods for measuring surface roughness are available in the literature and can be broadly classified into two categories: contact methods, such as photometers, and non-contact methods, such as scanning or optical microscopes [7, 8]. Surface roughness characterization can sometimes require the use of expensive devices that are not always available or justified. Therefore, this paper presents a methodology for analysing surface topography that is based on generating spatial surfaces by processing images obtained from an optical microscope.

2. METHODS

2.1 Surface topography parameters - theoretical background

Surface description is based on two fundamental approaches: morphology and topography. Morphology characterizes the texture and arrangement of materials and shapes on surfaces. Topography is used for quantitative surface characterization, enabling calculation of roughness parameters [9].

Surface roughness can be described using both two-dimensional and three-dimensional parameters, depending on whether the profile line or the entire surface is analysed (Fig.1). To achieve the most comprehensive surface characterization, various derived parameters are utilized, including spacing parameters, hybrid parameters, functional parameters, and others. These parameters are standardized in the ISO 25178-2 standard [10, 12].

The profile of the surface can be represented by a mathematical function (such as a spline or a polynomial) which can be described by a relation [12]:

$$y = f(x). \tag{1}$$

The most frequently considered 2D parameters are:

- Arithmetical mean deviation of the profile:

$$R_a = \frac{1}{L}|z|; \tag{2}$$

- Root mean square deviation of the profile:

$$R_q = \frac{1}{L}z^2; \text{ i} \tag{3}$$

- Maximum height of the profile:

$$R_z = \frac{P1+P2+...+P5-V1-V2-...-V5}{5}. \tag{4}$$

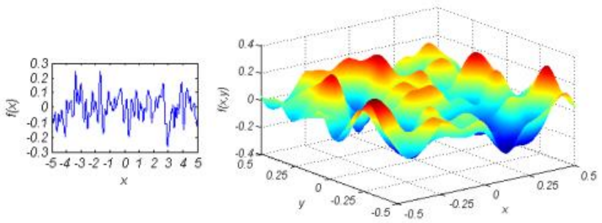

Figure 1. Line and surface parameters [11]

Given that the real world is three-dimensional, all surfaces are better described by 3D parameters, and in this way representative information is obtained. The description of surfaces is defined by a relation [10]:

$$z = f(x,y). \tag{5}$$

The most frequently considered surface parameters include:

- Arithmetic Mean Height:

$$s_a = \sum_{\text{n=1}}^{\text{N}} \frac{|Z_n - \bar{Z}|}{N}; \text{ i} \tag{6}$$

- Root Mean Square Height:

$$s_q = \sqrt{\frac{1}{\text{N}}\sum_{n+1}^{N}|Z_n - \bar{Z}|}. \tag{7}$$

The asymmetry and roundness of the surface are also frequently considered in addition to the previously mentioned parameters.

2.2 Experimental procedure

The testing algorithm is presented in Figure 3. The experiment was conducted using samples made of AlSi7Mg0.3 material and a CSM nanotribometer under the following conditions:

- movement: linear alternating,
- force: 0,3N, 0,6N i 0,9N;
- sliding speed: 3mm/s, 9mm/s i 15mm/s,
- amplitude: 1mm,
- sliding distnce: 10m, i
- number of cycles: 5000.

Since the test on the nanotribometer was intended to measure force and coefficient of friction, the topographical analysis of the sample was conducted in the MATLAB programming environment. To accomplish this, RGB images of the wear traks were captured using an MC-50T optical microscope and magnified 5x.

With the aim of easier image manipulation, RGB images were transformed into grayscale images (Fig. 3). By applying a suitable threshold, a clear visual separation of wear traks is achieved.

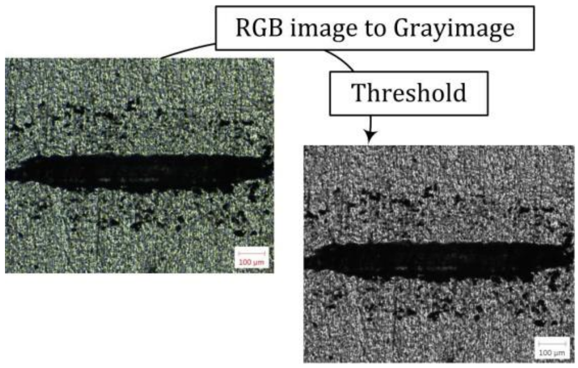

Figure 3. RGB image to grayimage transformation

The segmentation of the wear track made it more distinguishable from the surrounding surface, so the wear track was manually extracted (as shown in Fig. 4) and the topography parameters were only calculated for the extracted wear track.

Within the MATLAB programming environment, the image is viewed as a two-dimensional array, where sets of points in the x and y directions are defined. Therefore, surface interpolation on a discrete, rectangular grid defined by interval division can be performed (Fig. 5). The height dimension was determined based on the depth of penetration read from the device, which was 10 µm.

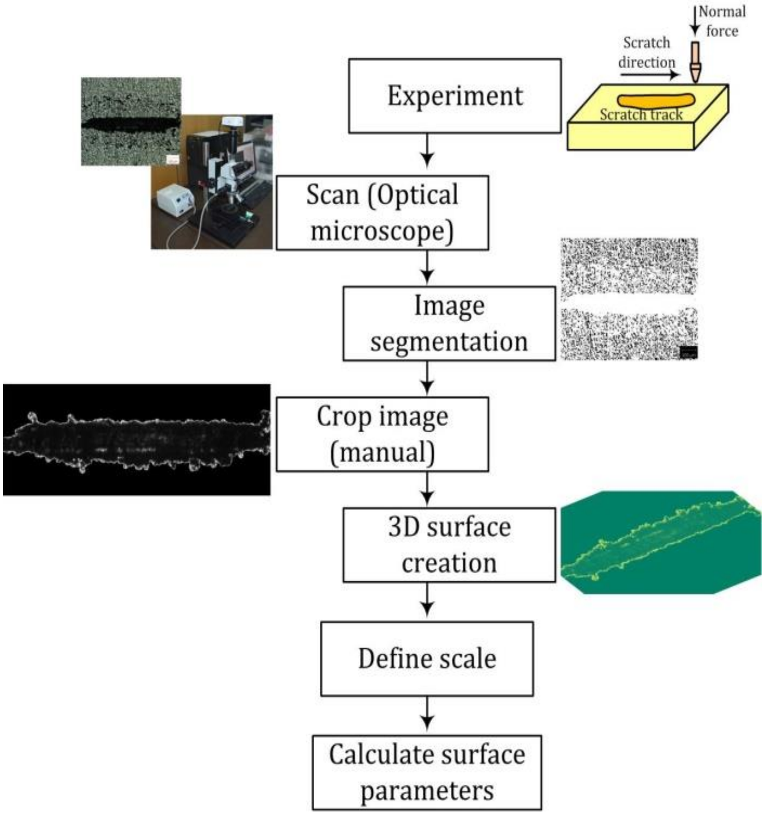

Figure 2. Algorithm of the experimental procedure

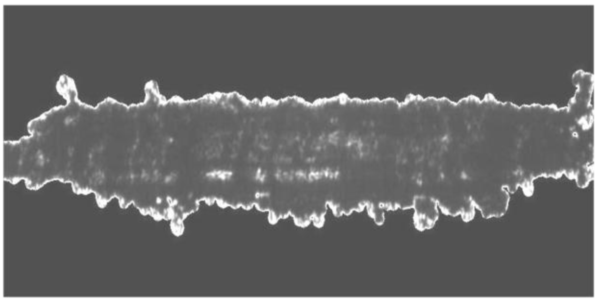

Figure 4. Manual image cropping

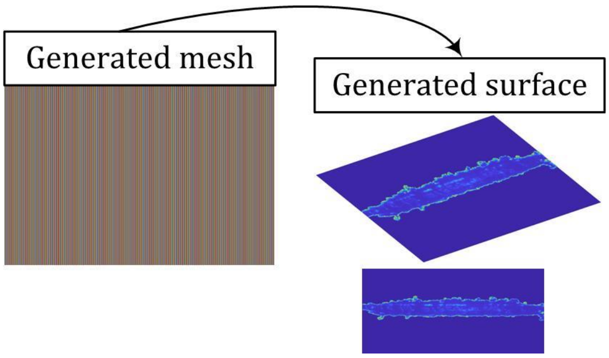

Figure 5. Spatial surface definition

The generation of the surface involves creating a mesh [X, Y] by using known ordered pairs from the x and y sets. This results in the formation of the contour of the wear track (Fig. 5). The height dimension is defined by the Z value, which is obtained by interpolating the function.

In order to obtain a smoother surface, spline interpolation is introduced, and additional surface control is provided.

3. RESULTS

The results show the values of both amplitude line and surface parameters in tabular form (Table 1). The arithmetical mean deviation of the profile observed from the perspective of line parameters is 0.6922 µm, while from the perspective of surface parameters it is 0.3771 µm.

Table 1. Roughness parameter values

Parameter	Value, µm
Ra	0.6922
Rz	2.4314
Rq	0.7622
Sq	0.856
Sa	0.3771

In addition to the mentioned parameters, the maximum height of the profile, as well as the root mean square deviation of the profile and the root mean square height, were also considered (Rz=2.4314 µm, Rq=0.7622 µm, Sq=0.856 µm).

Figure 6 displays the surface generated from the two-dimensional image, along with the profile line in the selected plane. The lowest values in the image are indicated by blue coloration (with a value of 0), while the raised areas are depicted with other colours.

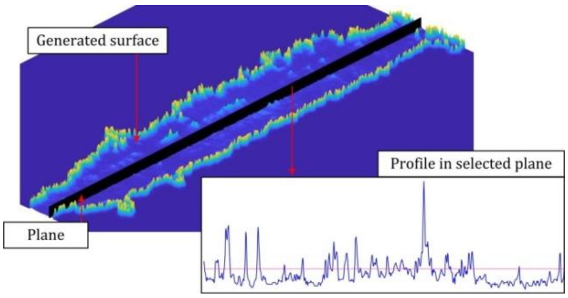

Figure 6. Spatial surface and profile in selected plane

In the selected plane, a surface profile line is displayed that has several amplitude jumps.

4. DISCUSSION

Surface roughness and topography, in tribological applications, is an important aspect for characterizing friction, wear and possible damage. Considering the surface as a compound structure, it is very complex to describe it with a limited number of parameters.

The most commonly used parameters for surface analysis are amplitude parameters. They are related to understanding friction, lubrication, and wear, as well as to the technical control of the production process [10]. A frequently used method for measuring surface roughness in industry is the use of a profilometer; however, this method has limitations related to the stylus tip diameter. As a result, many researchers are attempting to improve the process for determining surface roughness. For example, J. Mahashar Ali and M. Murugan proposed a method for determining surface roughness using vision-based image processing [13]. Similar to them, we also presented in this work a methodology for image processing, i.e. using two-dimensional images (obtained in laboratory conditions) we generated the spatial surface of interest and based on it, we determined selected parameters for characterizing the surface roughness.

Using optical microscope images for surface analysis has its advantages, such as lower cost and easier availability compared to other advanced microscopes like SEM or AFM [5,14]. However, optical microscopes have limitations in terms of resolution and magnification, which can affect the accuracy of the generated surface. Nonetheless, the methodology presented in this work shows that even with basic equipment, useful information about surface roughness and topography can still be obtained through image processing techniques.

The spatial surface generated from the two-dimensional images allowed us to visualize the surface topography and determine roughness parameters based on the heights of the surface irregularities. The lighter colours represented higher elevations or hills, while the darker colours represented lower elevations or depressions. By analysing the spatial surface, we were able to calculate roughness parameters such as average roughness, root mean square roughness, and maximum height of the surface irregularities. Lee, S. et al. also used spatial surfaces to investigate the effect of surface roughness on fatigue crack initiation and propagation in metallic materials. They observed that the presence of indentations on the surface led to an increased risk of fatigue crack initiation and propagation. This demonstrates the importance of surface roughness and its characterization in understanding material behaviour and failure mechanisms [15].

K. Singh et al. also pointed out the possibility of the occurrence of fatigue indentations analysing the surface images obtained on the SEM microscope, as well as the accompanying parameters. They determined the average roughness using optical surface profilometry [16]. In contrast to them, we determined the average roughness in the desired cross-sectional plane on the generated surface. In this way, we influenced the unification of the examination method.

5. CONCLUSION

In this paper, we have presented an approach for generating spatial surfaces based on 2D images and determining parameters for characterizing the surfaces under consideration. This methodology allows for the identification of hills and depressions formed on the material under defined contact conditions, as well as the prediction of possible damage caused under those conditions. Further research is focused on the automation of image segmentation and the derivation of additional surface characterization parameters.

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